MARBLED MURRELET MONITORING RESEARCH, 1998:

STUDIES ON DISTRIBUTION AND PRODUCTIVITY

OF MARBLED MURRELETS AT SEA IN OREGON

FINAL REPORT TO THE

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SUMMARY

Results of marine transects designed to sample Marbled Murrelet distribution, abundance and reproductive output on the Oregon coast during summer 1998 are summarized and compared with 1992-1997 surveys. Distribution was assessed by conducting coastline transects at 250 to 1100 m from shore in sample study areas of north, central, and southern Oregon, and by sampling offshore distribution using 4 km transects run parallel to shore at increasing distances out to sea. Field surveys were conducted between 10 June and 25 August, during which 2,418 km of transects were conducted.

During June and July, Marbled Murrelets densities within 1000 m of shore averaged 6.9 birds/km^2 in northern Oregon, 28.75 birds/km^2 in central Oregon, and 7.15 birds/km^2 in southern Oregon, based on 100m wide strip transects. The central Oregon densities were very similar to those of 1996 and 1997, but far less than in prior years. Northern Oregon densities were very similar to all other years, and southern Oregon had generally lower densities. Unlike other years, densities did not change much within regions during August, suggesting a reduced or delayed post-breeding dispersal. Densities at 1000 m offshore were similar to those at 500m during 1998.

Indicators of reproductive success were measured by ratios of the number of fledglings to older birds at sea, by ratios of densities of fledgling to older birds, and by the density of fledglings independent of older birds. Productivity indices were higher in central Oregon and lower in southern Oregon than in other years, but not appreciably different overall. The overall age ratio for surveys in late summer 1997 (after 20 July) was 50/2033 (2.40%). Common Murres and Pigeon Guillemot had low indices of productivity, particularly in southern Oregon, a consequence of ENSO conditions.

A comparison of methods to estimate distance of murrelets from the transect line indicated differences between direct estimates and those calculated from angle and distance-to-bird estimates. Both methods were useable for density calculations, however the direct estimate method had theoretical uncertainty, and the calculated method reduced search time for murrelets.

Comparison of DISTANCE program generated line transect densities with strip transects of several widths indicated that strips of approximately 70 m (35 m on either side of the vessel) closely approximate results of line transects. Strip widths of 100 m, as used for most Oregon surveys, were approximately 86 the density estimate of line transects. Line transects show promise in generating accurate densities with relatively low variance, but have the drawback of requiring more analysis time and not permitting multiple species comparisons.

A new technique for quantifying behavior differences between hatch-year and after-hatch-year murrelets suggested that at least 80% certainty in age determination could be obtained by behavioral characteristics.

INTRODUCTION

The value of marine surveys in obtaining critical information on the biology of the Marbled Murrelet has recently been appreciated, largely due to the decline of the species and the need to develop recovery and management plans (Ralph et al. 1995, USFWS 1997, Madsen et al. 1998). Because observations of abundance and reproductive success are not easily obtained in the forest nesting habitat of the Marbled Murrelet, at-sea methods of monitoring these parameters have been developed over the past 10 years (Carter 1984, Ralph and Miller 1995, Ralph and Long 1995, Strong et al. 1995, Becker et al. 1997, Kuletz and Kendall 1998, Strong 1998a). The methods employed in this research have been standardized for a 7 year period, with minor refinements each year to the survey strategy and observer procedure.

This report summarizes the results of 1998 research on at-sea abundance, distribution, and productivity of Marbled Murrelets in relation to prior years. Indices of productivity are included for Common Murres, Pigeon Guillemots, and Rhinoceros Auklets, since these sympatric alcid species provide a context in which to understand Marbled Murrelet productivity and ecology, and they allow some measure of the impacts of the 1998 ENSO event on seabirds in Oregon. Also included are comparisons of line versus strip transect density estimation, and preliminary analyses of two methods of estimating distance from the transect line. these methodological results are intended to supplement other research efforts in the development of a three state monitoring program under the Northwest Forest Plan Effectiveness Monitoring Program (Madsen et al. 1997).

METHODS

Survey Protocol

Surveys were made from 6 to 7 m long boats equipped with marine radio, compass, a Global Positioning System (GPS) unit, a digital sonar depth finder ('fishfinder'), and safety equipment. Other equipment included binoculars and digital watches and tape recorders with remote microphones for each observer. The deck of the boat was nearly level with the waterline, so observer viewing height was approximately 6 feet above water.

Two observers and a driver were on board. Each observer scanned a 90° arc between the bow and the beam continuously, only using binoculars to confirm identification or to observe plumage or behavior of murrelets. The focus of observations were within 50 m of the boat and up to 100 m ahead of the boat. All species of birds within 50 m of the boat and on the water were recorded. All Marbled Murrelets sighted at any distance were recorded with the following information:

A) Time of sighting to the minute.

B) Group size; a group being defined as birds within 2 m of each other or vocalizing to each other.
C) Side of vessel,
D) Estimated distance of bird(s) from the transect line, calculated in two ways (see below).
E) Behavior in one of 5 categories: fly in apparent response to the vessel, flying by in transit, dive in possible response to the vessel, forage diving (not in response to the vessel), and stay on the surface during vessel passage.
F) Age, molt condition and plumage notes, age of bird(s), and noteworthy behavior, such as fish carrying, vocalizing, or unusual flight or diving behavior.

Distance from the transect line was estimated in two ways; by judging the distance off the line by eye (usual method), and by estimating the distance to the bird by eye and the angle of the bird off the line, and later calculating the distance off the line as *sin* <*(distance to bird). The second method was used in a subsample of paired observations with the first, using different and alternating observers between the methods (to avoid the systematic bias possible with single observer/method comparisons). Paired observations were only conducted where murrelet densities were moderate or low and conditions were good, so as not to interfere with detecting other birds.

Estimates of distance to murrelets were calibrated by deploying reference floats at 50, from the vessel periodically through each season. In addition, a series of tests were run to obtain an estimate of variability in distance estimation (see Becker et al., in prep.) and further improve our estimation ability. Position along the coast was determined when passing landmarks on shore and with the GPS. Speed was maintained at approximately 10 knots at all times, and location was interpolated between known points using time elapsed while traveling at known speed. Distance from shore was visually estimated when within 800 m and with the GPS when farther offshore.

Environmental variables monitored included surface water temperature, depth, presence of sonar scattering layers, rip currents, type of shoreline (categorized as rocky, sandy beach, mixed rock and sand, and within 1-2 km of river mouths), and weather conditions. Weather conditions included wind, Beaufort sea state, cloud cover, swell height, and observing conditions. Observing conditions was a composite variable incorporating weather and lighting conditions as they affected detectability of murrelets. Observing condition correlated closely with wind and beaufort sea state. Surveys were not initiated at Beaufort state 3 (fair observing conditions), and surveys were usually terminated at Beaufort state 4 (poor observing conditions), although some poor condition observations were made for comparison of detection curves with other observing conditions.

All observers were trained in survey protocol during initial surveys each year. Experiences observers (2+ full seasons experience) were on board during all surveys. Rest stops were taken at least every 4 hours to reduce observer fatigue. Drivers were not expected to actively participate in searching for birds, but did report detections to observers incidentally. All information was recorded on cassette tapes via an external microphone, held by one of the observers. Data were later transcribed to data sheets and then entered in DBASE on computer.

Study areas

Survey coverage was devoted to three areas of the Oregon coast, each approximately 100 km in length, in an effort to refine abundance estimates with replicate surveys.

Transects of the northern Oregon coast were conducted between Tillamook Head (45° 55') and Cascade Head (45° 05'). This area is adjacent to somewhat fragmented inland habitat retained primarily in coastal state parks and the Tillamook and Clatsop State Forests.

The focal area for central Oregon surveys (established since 1992) was between the Siletz River (44° 55' N) and Florence (44° 01' N). Marbled Murrelet nesting habitat inland from this coastline is largely contained within the Siuslaw National Forest.

southern Oregon study area included the coast between the Rogue River (42° 25' N) and Point St. George, California (41° 47' N). This region has different oceanographic and coastal habitat characteristics from those of central and northern Oregon (Landry and Hickey 1989). Forest habitat inland from this coast is contained within the Siskiyou National Forest.

Survey Coverage

To quantify distribution along the length of the coast, a *coastline* transect was conducted parallel to the shore between ports or in a round trip. If between ports, distance to shore was maintained at 400 to 700 m; if on a round trip, two nearshore lines were surveyed; at 500 m and at 1000 m. a few coastline surveys were also conducted at 250 m and 1500 m offshore.

Surveys were conducted from 10 June to 25 August. Priority was given to obtaining eight replicate surveys of the central Oregon area. Three replicates of the northern area and four of the southern area were also completed, but, due to weather, surveys did not always cover the entire sample area (Table 1).

To quantify distribution in relation to distance from shore, *offshore* transect lines along the same 4 km section of coast were run, each one 500 m farther out to sea than the previous one. Transect lines were repeated out to 2000 m offshore and then at 2500, 3500, and 4500 if any murrelets were seen on the water at 2000 m. Samples of offshore distribution were selected prior to initiating the day's survey to avoid a potential bias to preferentially conduct offshore samples at higher density areas. Offshore samples were conducted at a variety of locations to represent each region of the coast.

Age Determination

The plumage of fledgling Marbled Murrelets at sea is very similar to the basic plumage of older birds. The prebasic molt of Marbled Murrelets can begin as early as late June, but progresses slowly, so that few, if any, birds have completed molt by late August. Difficulty in age determination does not arise until AHY birds are in an advanced stage of prebasic molt. Prior to August, HY Marbled Murrelets were easily told from older birds by bright white feathers on the belly, epaulets, and neck, compared with the overall darker appearance of partially molted AHY birds. We tracked the progression of AHY molt through the season by categorizing the molt state of all murrelets detected as follows:

CLASS 1) Very little or no molt, entirely in alternate plumage.

CLASS 2) Obvious body molt with lighter neck and body color, but estimated at less than 50% of alternate plumage lost or replaced.

CLASS 3) Over 50% of alternate plumage lost or replaced, but still clearly distinguishable from HY birds by brown feathers on back, breast, and belly. Molting birds were placed in class 3 if their throat and neck appeared whitish in overall color.

CLASS 4) Appears to be in basic plumage when seen from a distance. By definition class 4 birds were those that required close examination to verify age. This class included all HY as well as advanced-molt AHY birds.

When birds in plumage class 4 (C4, advanced prebasic molt) were detected, the transect was halted and we approached more closely to record age determining characteristics. Characteristics that qualified a C4 bird as AHY were a) presence of dark brown alternate plumage feathers on back, neck, or breast, visible when viewed closely; b) presence of dark alternate plumage on the belly seen as it dove; or c) missing or molting flight feathers. Characteristics that qualified a bird as HY were a) crisp black and white plumage, sometimes with fine speckling on the breast; b) crisp plumage combined with an entirely white belly; and c) full, non-molting wings combined with other characteristics. The usefulness of these criteria was date-dependent and changed through August; presence of full, non-molting wings was the only conclusive criteria by late August, when all but the flight feathers of some AHY birds had been replaced with basic plumage. our certainty of age determination dropped after 20 August since we felt some AHY birds could have been in full basic plumage by this time (see also Strong 1996).

In August, transects were interrupted more and more frequently as the month progressed in order to examine birds in C4 molt. Transects resumed after every examination of a C4 bird and proceeded until the next C4 bird was encountered or the line was completed. Because of the frequent pauses, transects after 15 August were considered less accurate for calculating densities.

Behavior of HY versus AHY has been noted to differ (Strong 1998a). We tallied the number of instances in which C4 birds flapped or did not flap their wings after surfacing from their first dive in response to the vessel's presence. This data was collected on an arbitrary sample of 110 C4 AHY birds for which age was determined by plumage, and on 33 confirmed-age HY (all those for which we remembered and had the opportunity to observe the behavior).

Data Management and Analyses

Monthly density of murrelets in the 3 study areas were computed as the mean of surveys within 1200 m of shore, divided into 2 km long by 100 m wide strip segments (all murrelet detections within 50 m of the transect line on the water divided into 2 km bins of survey transect; the segments allow an estimate of variance in abundance along the coast).

To assess the difference between methods of density estimation, data from June and July data were divided into 30 data sets with based on region, date, and distance from shore. Each data set was edited to include observations only in good to excellent viewing conditions, and the length of transect carefully delineated. Densities were generated using fixed strip widths of 30, 40, 50 , and 60 m out from the boat, an effective strip width of 100m, and using line transect analysis. Effective strip widths use all detections and assume a strip width where detections beyond the specified strip compensate for missed birds within the strip. Line transect analyses were performed by program DISTANCE (Laake et al. 1993, v. 2.0) with initial selections and model-fitting choices within the ESTIMATE module made as follows:

distance /width=140;
gof /nclass=7;
monotone=weak;
detection by stratum;
density by sample;
estimator;
estimator /key=unif/adj=poly;
estimator /key=hazard/adj=poly;
estimator /key=nexpon/adj=poly;
estimator /adj=herm;
end;

Other curve fitting and modeling procedures used the default settings of the program.

To assess productivity, I averaged the ratio of HY:AHY by month and for all surveys after 20 July (when most HY are present at sea). The mean monthly density of HY and AHY were calculated and ratios of the density of HY:AHY at their peak month of occurrence were used as an additional means of assessing productivity (this addresses post-breeding dispersal, see Kuletz and Kendall 1998). We used the same peak monthly density ratios to compare indices of productivity between other alcid species and Marbled Murrelets. Densities for the productivity assessment were calculated from the total birds seen divided by total kilometers of survey conducted in each month, using fixed 100 m strip transects.

RESULTS

Survey Effort

Surveys were conducted on 29 days from 10 June to 23 August. A total of 1,633 km of coastline surveys were conducted (417 in northern Oregon, 785 km in central Oregon, and 431 km in southern Oregon), and 270 km of offshore sampling surveys (>1200 m) were completed in 22 samples at various locations (Table 1).

Table 1. Summary of daily survey coverage and number of Marbled Murrelets seen during 1998 in the north (Nor), central (Ctr), and south (Sou) study areas along the Oregon coast. Surveys were done between given latitudes (Coast, within 1200 m of shore) or for the northern end of the sampling area of offshore samples (Off, >1200 m offshore). Kilometers shows the extent of survey. All murrelet detections are included in Total, only confirmed age murrelets are included in AHY (after yatch-year) and HY (hatch-year) tallies.

	COVERAGE				MURRELETS		
DATE	Region	Type	Latitudes N	Kilometers	Total	AHY	HY
Jun 13	Ctr	Coas	44°37' 44°44'	17.5	23	21	0
Jun "	Ctr	Off	44°44'	12	0	0	0
Jun 14	Ctr	Coas	44°37' 44°01'	71	312	286	0
Jun "	Ctr	Off	44°22'	12	13	12	0
Jun 15	Sou	Coas	42°03' 41°54'	26	32	27	0
" "	Sou	Off	42°01'	16	25	25	0
Jun 18	Sou	Coas	41°45' 41°51'	20	75	69	0
" "	Sou	Off	41°51'	12	20	19	1
Jun 22	Nor	Coas	45°34' 45°56'	100	85	81	0
" "	Nor	Off	45°50'	8	0	0	0
Jun 23	Nor+Ctr	Coas	45°34' 44°48'	102	299	283	0
" "	Nor	Off	45°33'	12	14	14	0
Jun 24	Ctr	Coas	44°37' 44°48'	31	45	42	1
" "	Ctr	Off	44°48'	8	0	0	0
Jun 26	Ctr	Coas	44°37' 44°18'	35	316	291	0
Jun 29	Sou	Coas	41°44' 42°03'	48	40	39	0
" "	Sou	Off	41°55'	20	38	38	0
Jun 30	Sou	Coas	42°03' 42°25'	109	40	39	0
" "	Sou	Off	42°23'	8	1	0	0
Jul 5	Ctr	Coas	44°37' 44°34'	10	48	45	0
" "	Ctr	Off	44°35'	16	17	16	0
Jul 6	Ctr	Coas	44°21' 44°53'	83	361	332	3
" "	Ctr	Off	44°52'	8	0	0	0
Jul 14	Ctr	Coas	44°37' 44°46'	26	81	74	0
" "	Ctr	Off	44°44'	4	3	3	0
Jul 15	Ctr	Coas	44°48' 44°55'	25	91	11	1
" "	Ctr	Off	44°44'	8	0	0	0
Jul 16	Nor	Coas	45°34' 45°56'	97	133	109	1
" "	Nor	Off	45°32'	8	2	2	0
Jul 17	Nor+Ctr	Coas	45°34' 44°48'	102	160	126	2
" "	Nor	Off	45°25'	8	0	0	0
Jul 18	Ctr	Coas	44°01' 44°22'	62	622	499	2
Jul 22	Sou	Coas	41°44' 42°03'	62	251	205	5

Table 1, continued

DATE	COVERAGE Region	Type	Latitudes N	Kilometers	MURRELETS Total	AHY	HY
" "	Sou	Off	41°48'	18	8	8	0
Jul 29	Ctr	Coas	44°37' 44°56'	81	272	250	5
" "	Ctr	Off	44°40'	20	8	8	0
Jul 30	Ctr	Coas	44°37' 44°01'	76	475	403	3
" "	Ctr	Off	44°06'	12	4	3	0
Aug 3	Sou	Coas	42°25' 42°03'	60	149	135	4
" "	Sou	Off	42°13'	12	2	2	0
Aug 4	Sou	Coas	42°03' 41°59'	10	40	36	1
Aug 14	Ctr	Coas	44°37' 44°36'	4	14	11	1
Aug 15	Nor	Coas	45°34' 45°56'	78	34	24	4
" "	Nor	Off	45°51'	8	0	0	0
Aug 16	Nor+Ctr	Coas	45°34' 44°48'	93	127	109	10
" "	Ctr	Off	45°01'	12	9	9	0
Aug 17	Ctr	Coas	44°48' 44°25'	92	403	327	9
" "	Ctr	Off	44°48'	8	0	0	0
Aug 18	Ctr	Coas	44°03' 44°17'	62	125	115	1
" "	Ctr	Off	44°13'	8	0	0	0
Aug 22	Ctr	Coas	44°37' 44°03'	75	415	333	5
" "	Ctr	Off	44°22'	12	2	1	1
Aug 23	Sou	Coas	42°25' 42°03'	54	68	54	1

Distribution and Abundance

The large scale pattern of Marbled Murrelet abundance was similar to prior years; they occurred at relatively low densities in the northern region (6.90 birds/Km^2, sd=11.15, n= 164 sections of 2 km transect), at highest densities in the central region (28.75 birds/km^2, sd= 32.70, n= 319), and in low overall densities in the southern region (7.15, sd= 13.10, n= 104). The low densities in southern Oregon relative to earlier may have been due to a small sample size there during July (Table 2). Densities in the central region were similar to 1996 and 1997, but lower than in earlier years. The above density values are an average of June and July surveys; August surveys were not included due to the possibility of post-breeding dispersal affecting estimates of abundance (see Strong and Fisher 1998). However, August densities this year were similar to those of June and July.

In 22 samples of distribution offshore completed in 1998, peak abundance was found at 500 m on 11 surveys, at 1000 m on 6 surveys, and at 1500 m on 5 surveys (Table 3). On

Table 2. Average monthly density of Marbled Murrelets for 3 regions of the coast, 1992-1997. Densities are in km^2, based on 2 km by 100 m fixed strip coastline transect segments. x= mean, s= standard deviation, n= number of 2 km segments surveyed.

	NORTHERN			CENTRAL			SOUTHERN		
	x	s	n	x	s	n	x	s	n
1992 June	7.20	17.00	75	84.65	77.85	259	10.40	15.05	12
July	5.40	11.25	40	84.20	89.4	87	23.60	31.25	101
August	6.05	8.05	33	35.25	49.4	117	no data		
1993 May	3.40	6.70	37	13.40	20.25	136	no data		
June	7.15	13.90	23	49.25	68.15	175	23.00	25.65	25
July	17.45	28.35	70	31.25	39.50	207	6.30	12.4	74
1994 August	7.15	17.85	72	29.15	31.50	124	30.85	35.60	92
1995 June	no data			49.00	39.10	50	20.30	27.05	112
July	8.30	14.30	77	67.20	61.70	132	25.80	40.75	19
August	3.60	8.25	68	39.85	49.10	118	18.25	20.75	91
1996 July	6.65	9.90	82	34.65	62.60	137	13.70	19.05	131
August	5.35	9.50	68	24.75	34.45	219	18.90	28.91	89
1997 June	7.20	15.15	25	36.00	38.55	107	4.60	11.25	76
July	7.20	13.65	64	23.25	46.40	225	6.60	16.15	82
August	2.75	5.35	38	18.90	17.35	49	20.65	33.85	60
1998 June	7.65	11.81	83	32.25	33.17	84	5.70	11.06	104
July	6.15	10.43	81	27.45	32.40	235	18.45	20.51	13
August	5.80	13.52	73	29.30	32.27	132	13.25	19.4	63

coastline transects, densities were similar between 500 m and 1000 m offshore. The 500 m line ranged from 12.2 % higher (in southern Oregon) to 6.5% lower (in central Oregon) in mean density relative to the 1000 m transect line (ns differences by Mann-Whitney U tests for each region). Numbers dropped sharply on surveys beyond 1500 m in all but four surveys; two of

Table 3. Summary of offshore distribution samples collected in 1998. The left column is the category of distance offshore in meters. Other columns each represent an offshore survey with values showing the number of murrelets within 50 m of the transect line on the water at that distance category. See Table 1 for latitude at the north end of each 4 km sample area. Blanks occur where no survey was conducted at a distance category.

Region	Ctr	Ctr	Sou	Sou	Nor	Ctr	Sou	Ctr	Ctr	Ctr	Nor
Date	6/13	6/14	6/15	6/18	6/22	6/24	6/29	7/05	7/06	7/14	7/16
4500							0				
3500			0				0	0			
2500	0	0	5	0			3	5		0	
2000	0	0	3	7	0	0	6	2	0	3	0
1500	0	11	10	11	0	0	7	7	0	0	0
1000	3	9	0	23	2	0	3	9	0	2	0
500			0	7	2	8	2	25	10	23	8
200									7		

Region	Ctr	Ctr	Sou	Sou	Nor	Ctr	Sou	Ctr	Ctr	Ctr	Nor
Date	7/17	7/18	7/22	7/29	7/30	8/03	8/15	8/16	8/17	8/18	8/22
4500				0							
3500				0							
2500		0	0	4	0	0		0			0
2000	0	0	0	0	0	0	0	0	0	0	0
1500	0	4	6	2	1	0	0	9	0	0	2
1000	3	27	4	7	15	0	0	6	3	19	18
500	1	30	2	16	10	17	5	3	13	2	17
200				5					5		

these were in the south region (south of Brookings and in Pelican Bay, California) and two were in the vicinity of the Yaquina River mouth. The general distribution pattern was most similar to 1997; disbursed somewhat farther offshore than most other years (except 1993). We did not find large increases in density close to rocky shores late in the nesting season, as has characterized other years (Strong 1998b).

Hatch-year Distribution

Hatch-year Marbled Murrelets showed a tendency to be closer to shore than the overall murrelet population. Of 61 HY detected in 1998, 48 were on the inshore coastline survey (<700 m out), 10 were at 1000 m, and 3 were seen at 1500 m offshore. As in other years, highest densities of HY occurred less than 500 m offshore along rocky coastlines where deeper water, and often kelp, were present (see Strong 1998b, Strong and Fisher 1998, further analysis pending).

Productivity

AHY Molt and Age Determination

The progression of molt among after hatch-year murrelets was similar to that of 1997; one individual AHY was in advanced molt (C4) on 7 July, but advanced molt AHY were not seen regularly until 29 July and later. Some AHY murrelets were in their final stages of molt by 17 August (completed body molt, new outer primaries nearly at full length), and there was increased uncertainty in some age determinations after this. In spite of the earlier molt of many birds in 1997 and 1998, a few remained in alternate plumage (C1) until the end of the field surveys.

A majority of AHY C4 murrelets would flap their wings upon surfacing after being pressed into diving by our vessel, whereas this was a rare behavior among HY murrelets. Of 108 C4 murrelets which were confirmed as AHY age by plumage characteristics in which the flap/no flap behavior was quantified, 88 (81.5%) flapped their wings following the dive. None of the 33 HY (with age confirmed by plumage) for which the behavior was checked flapped following the first dive. The presence of flapping behavior, then, corresponds to an approximate 80% probability of C4 bird/s being AHY.

Age of C4 birds was determined in 148 of 183 cases (81%) in 1994, 478 of 522 cases in 1995 (91%), 275 of 302 cases in 1996 (91%), 120 of 143 cases in 1997 (84%), and . The undetermined age birds were either lost to view, confused with other birds, or in a plumage where age could not be determined in the field. Of aged C4 murrelets, 50, 100, 64, 67, and 62 were identified as HY in 1994, 1995, 1996, 1997, and 1998 respectively.

Measures of Productivity

The overall HY/AHY ratio on coastline surveys after 20 July in 1998 was 49:2003 (2.39%). Inclusion of the offshore data changed the ratio only slightly to 50:2033 (2.40%, data summed from Table 1). Because AHY may move from breeding areas late in the season, the ratio of HY/AHY densities at their respective month of peak density was used as another measure of reproductive success, as was the absolute density of HY independent of AHY (see Kuletz and Kendall 1997). Both HY:AHY ratios and temporally staggered density ratios in 1998 were higher than the previous two years in northern and central Oregon, but lower in southern Oregon (Tables 4,5). Hatch-year densities were similar in all 3 regions at 0.58 to 0.77 fledglings per Km^2. This is in contrast to prior years, in which southern Oregon had the highest HY densities, and central Oregon had the lowest HY density.

Comparison with Other Alcids

Regional differences in marine productivity are apparent in the age ratios of alcid species, and reduced Marbled Murrelet productivity in the southern region was corroborated by productivity indices of other seabirds. No Common Murre HY were seen at sea in the southern region during 1998. Common Murres had relatively poor productivity in northern and central Oregon in 1996 and in northern Oregon in 1997. In 1998 the pattern was reversed, with the highest productivity in the north (Table 5). Above average sea-surface temperature, low upwelling indices, and relatively poor murre productivity have characterized the past 3 years in

Table 4. Summary of monthly Marbled Murrelet HY/AHY age ratios for 3 regions of the Oregon coast from 1992 to 1998. In parentheses are percent HY. ND = no data.

	MONTH			
	June	July	August	September
Northern Region, Columbia River to Cascade Head				
1992	3/120 (2.44)	1/51 (1.92)	9/70 (11.39)	ND
1993	0/53 (0.0)	6/346 (1.70)	ND	ND
1994	ND	ND	5/99 (4.81)	ND
1995	ND	3/193 (1.53)	13/82 (13.68)	ND
1996	ND	4/197 (1.99)	7/91 (7.14)	ND
1997	0/57 (0.0)	0/182 (0.0)	4/51 (7.27)	ND
1998	0/233 (0.0)	1/166 (0.60)	9/93 (8.82)	ND
Central Region, Cascade Head to Coos Bay				
1992	6/5,993 (0.10)	26/2,501 (1.03)	62/1,352 (4.38)	ND
1993	4/3,427 (0.12)	19/3,024 (0.62)	ND	ND
1994	ND	ND	24/815 (2.86)	ND
1995	2/980 (0.20)	10/2,759 (0.36)	34/1,258 (2.63)	ND
1996	ND	3/1,446 (0.21)	21/1,558 (1.33)	2/54 (3.57)
1997	0/1631 (0.0)	28/1864 (1.48)	5/261 (1.88)	ND
1998	1/796 (0.13)	16/1715 (0.92)	22/826 (2.59)	ND
Southern Region, Coos Bay to California				
1992	0/33 (0.0)	17/770 (2.16)	ND	ND
1993	0/147 (0.0)	3/151 (1.95)	ND	ND
1994	ND	ND	21/586 (3.46)	ND
1995	3/938 (0.32)	2/169 (1.17)	15/401 (3.61)	18/336 (5.08)
1996	0/89 (0.0)	9/469 (1.88)	17/396 (4.112)	ND
1997	0/226 (0.0)	10/180 (5.26)	17/340 (4.76)	ND
1998	1/256 (0.39)	5/213 (2.29)	6/227 (2.56)	ND

Table 5. Densities of 4 alcid species in 3 regions of the Oregon coast from 1996 to 1998, separated into After-Hatch-Year and Hatch-Year per km^2 during their peak month of abundance. Ratio is the density of HY/AHY at their monthly peak, in parentheses is the total number of birds on which the ratio was based.

	Species			
	Common Murre	Pigeon Guillemot	Marbled Murrelet	Rhinoceros Auklet
	AHY HY	AHY HY	AHY HY	AHY HY
Northern Region				
1996				
Densities	63.76 0.59	18.75 0.22	6.65 0.510	0.56 0.37
Ratio (n)	0.009 (1092)	0.012 (258)	0.077 (120)	0.661 (13)
1997				
Densities	82.39 0.667	17.35 1.467	7.21 0.533	0.598 0.133
Ratio (n)	0.0081 (969)	0.0845 (214)	0.0739 (189)	0.223 (8)
1998				
Densities	76.78 14.00	18.97 0.64	7.65 0.770	1.28 0.90
Ratio (n)	0.182 (1634)	0.034 (306)	0.101 (139)	0.703 (38)
Central Region				
1996				
Density	86.51 0.79	6.44 0.22	32.74 0.38	1.60 0.13
Ratio (n)	0.009 (2570)	0.034 (200)	0.012 (977)	0.081 (96)
1997				
Density	34.31 2.23	8.95 1.75	36.65 0.559	3.92 0.28
Ratio (n)	0.065 (1721)	0.195 (153)	0.0152 (1312)	0.071 (60)
1998				
Density	47.36 1.07	8.63 0.68	32.25 0.640	3.83 0.61
Ratio (n)	0.023 (2356)	0.079 (440)	0.020 (561)	0.159 (131)
Southern Region				
1996				
Density	25.61 0.81	10.65 1.38	25.29 1.38	6.49 0.19
Ratio (n)	0.032 (914)	0.130 (165)	0.055 (368)	0.029 (206)
1997	69.83 4.34	11.38 1.03	20.65 1.25	13.46 0.22
Density	0.062 (1274)	0.09 (162)	0.061 (347)	0.016 (178)
Ratio (n)				
1998				
Density	54.52 0.00	9.04 0.19	18.45 0.58	2.21 0.29
Ratio (n)	0.000 (567)	0.021 (96)	0.031 (54)	0.131 (26)

*July 31 data are included in the August sample as they were more representative of that period.

Oregon on a statewide level (Lowe, USFWS pers. comm., Strong and Fisher 1998). the density ratio of Pigeon Guillemots was also lowest in southern Oregon in 1998. Rhinoceros Auklets did not appear to be so affected; HY densities in all 3 regions were comparable with other years (Table 5). Rhinoceros Auklet data is difficult to interpret, however, since an unknown and variable portion of the population occurs well offshore.

Methodology

Distance Estimation Comparisons

Through the course of 1997 and 1998 I collected a sample of 186 and 197 murrelet detections, respectively, in which distance off the transect line was estimated both by direct estimation and by estimating the distance to the bird and the angle of the bird off the transect line, after which the distance could be calculated. The mean directly estimated distance was 34.69 m (s.d. = 29.82, n = 383), not significantly different from the mean calculated distance of 35.66 m (s.d. = 28.82, n = 383). Within 50 m of the line, the direct estimate method tallied 307 detections, where the calculated method tallied 294, corresponding to densities of 52.3 birds/Km^2, and 51.9 birds/Km^2, respectively. Line transect density estimates produced densities of 65.4 and 55.4 birds/Km^2 for direct and calculated distance estimates, respectively. The line transect values were similar to densities generated with smaller strip transects (Table 6).

Methods of calculating density

Line transect density values were most similar to the 60 m wide strip transect measures for 29 of the 30 samples I ran (Table 7). The relation of estimated density to strip width closely followed a linear relationship ($^2 = 0.92$) in which strip transect densities were equal to those of line transects at about 35 m (Fig. 1). Densities calculated from 100 m wide strip transects (as used in many Oregon surveys) averaged 86% of that for line transects (std. dev. = 30%, n = 29). Paired *t* tests between each strip width and line transect densities showed no significant difference for the 60 and 80 m wide strips (30 and 40 m out from either side of the vessel), but they were different at 100 m (t= -2.78, p=0.0095) and at 120 m or 200 effective strip ($p< 0.001$). Effective strip transect calculations for 200 m produced only 49% the density of line transects, but observer search effort would be different if the objective were to conduct effective strip transects properly (without a biased effort near the transect line).

Individual transect lines (data points in the above comparison) varied quite at bit between strip and line methods, but overall correlation between any strip width and line was very high (R^2 >0.88 in all cases). Differences did not appear to be associated with transect length. In fact, DISTANCE performed well in calculating densities for small sample sizes in general. The program gave clearly erroneous results in 5 of the 30 cases however; where many detections were clustered close to the transect line, DISTANCE selected *hazard* or *negative exponential* key models which shot the density estimate up beyond reason on the transect line. This occurred even though the Chi square fit of the model was quite good. By removing these optional key models, the program gave reasonable results. Even for models which gave 'reasonable results', *hazard* or *negative exponential* models produced densities up to 52% higher than *half-normal.*

Table 6. A comparison of Marbled Murrelet densities generated from three strip widths and line transect analysis using a subset of 380 murrelet detections where distance from the transect line was estimated in two ways (see methods). Hypothetical transect length was set at 100m.

Line distance estimation method	Density calculation method			
	50 m strip	40 m strip	30 m strip	line
Estimation off the transect line	52.3	58.25	63.65	65.4
Estimation of angle and distance to bird	51.9	56.75	58.85	55.4

DISCUSSION

Distribution, Abundance, and Productivity

There was an inverse relationship between Marbled Murrelet occurrence offshore and their coastline densities during the 1992-1995 surveys, but since 1996, densities have been relatively low for both coastline and offshore distributions in central Oregon. The more recent data for the central Oregon coast is more thorough in terms of replicate coverage and number of offshore distribution samples. This strengthens the the conclusion that the current central Oregon murrelet population is reduced from that in 1992-1993.

A significant El Nino Southern Oscillation (ENSO) event affected primary productivity all along the west coast in 1998, and in both 1996 and 1997 oceanographic conditions off central and northern Oregon were indicative of low primary productivity as well. A question remains on what extent the decline in central Oregon is due to marine conditions versus possible long term depletion of nesting habitat in central Oregon. If large amounts of nesting habitat were removed from Siuslaw National Forest in the late 1980's (S. Madsen pers. comm), the lack of recruitment, and senescence of adult murrelets, may only recently be affecting the total population in this long lived species (see also Strong 1996).

Through 1997, a density decrease of Marbled Murrelets occurred in August in central Oregon, and a corresponding increase occurred in southern Oregon (Strong 1998b). In 1998, densities were relatively more consistent in both regions (Table 2) indicating that the 'usual' post-breeding shift in distribution was delayed or altered. I suggest that this, and the relatively higher productivity indices of central Oregon this year, are a result of some murrelets avoiding the southern Oregon region, which was most severely impacted by the ENSO event (evidenced by a lack of Common Murre productivity, see Jaques and Strong 1999).

Table 7. A comparison of Marbled Murrelet densities (murrelets/km^2) calculated from 30 transect samples using different strip widths and line transect analyses. Region N is northern Oregon, C is central Oregon, S is southern Oregon; see methods for areas included and a description of '200 m effective strip transect.

Date	Region	Distance from shore	Transect length (km)	Strip width 60 m	80 m	100 m	120 m	200 m eff	Line transect
6/22	N	500	49	6.12	6.12	5.51	5.44	5	5.35
7/16	N	500	70	7.14	8.04	7.57	7.26	6.86	7.59
6/22	N	1000	53	4.4	3.54	3.4	3.46	2.92	4.25
7/16	N	1000	30	3.89	4.17	3.33	3.61	2.67	4.7
7/29	C	500	47	31.93	27.36	29.89	26.83	19.79	25.86
7/14	C	500	9	18.52	16.67	13.33	13.88	11.11	19.52
7/30	C	500	75	58	53.5	50.93	48.31	43.73	56.9
7/05	C	500	6	75	62.5	50	43.04	28.33	62.71
7/15	C	500	12	22.22	16.67	15.83	15.27	9.58	21.93
7/18	C	500	42	62.7	55.95	48.57	45.22	46.79	72.71
7/06	C	500	41	26.42	22.56	18.53	18.69	15.37	31.13
6/26	C	1000	23.5	63.82	62.23	56.17	51.75	37.23	55.3
6/14	C	1000	33.5	32.34	39.18	37.01	37	29.55	41.49
7/29	C	1000	16	33.33	25	21.87	22.39	19.68	25.82
7/18	C	1000	19.5	72.65	73.08	70.76	64.93	58.72	81.01
6/14	C	1500	8	6.25	12.5	15	14.58	16.88	180.4*
7/22	S	500	36	6.02	5.21	4.72	5.32	6.94	8.67
6/30	S	500	56	3.57	4.46	4.11	3.57	2.68	3.2
6/29	S	500	44	7.57	7.67	6.14	5.11	3.52	5.04
6/18	S	500	11	9.09	6.82	7.27	9.84	8.64	10.66
6/15	S	500	16	2.08	1.56	1.25	1.04	1.88	2.54
6/15	S	1000	8	0	0	0	0	0.63	0.96
6/30	S	1000	53	1.26	0.94	0.75	0.63	0.85	0.61
6/18	S	1000	9.5	33.33	38.16	37.89	36.83	28.42	29.92
6/29	S	1000	4	12.5	9.38	7.5	6.24	3.75	12.5
7/22	S	1000	17	33.33	27.21	25.29	23.03	20.59	27.67
7/22	S	1500	8	33.33	39.06	32.5	31.24	25.63	44.01
6/29	S	1500	4	25	21.87	17.5	20.82	15	26.31
6/18	S	1500	4	33.33	34.38	27.5	22.91	13.75	18.14
6/15	S	1500	4	25	18.75	25	20.82	17.5	23.86
Mean percent of line density				103.9	95.4	85.8	81.2	71.3	100.0

* This data set removed from analysis since reasonable line transect density could not be computed.

Methodology

From the sample of matched estimates of distance from the transect line using direct estimation versus estimates of distance to the bird and angle off the line, it is apparent that both methods are useable in calculating densities by either line or strip transect analysis. I have no information on which method is more accurate, although the distance-to-bird and angle method may be more theoretically defensible. Because the direct estimation method is faster, allowing more search time, I recommend continuing its use, particularly at high murrelet densities where increased search time increases detections.

Densities of murrelets using fixed 100 m wide strip transects averaged 85.8 % of line transects in the analysis here (n = 29). Becker et al. (1997) found strip transects averaged 81.75% of line transect densities (n= 47); Strong (1996) found strip transects to estimate 93.6% the density as line transects (n= 9), and Strong et al. (1995) had strip transect densities averaging 87.5% that of line transects (n= 8, all source comparing 100 m fixed transect widths to DISTANCE-calculated line transect densities). These comparisons provide some idea of a correction factor that could be applied to strip transect densities as used in Oregon over the past 8 years to represent what would be found by line transect analysis. Alternatively, a narrower strip width could be selected based on an analysis such as in Fig 1, or the data could be processed with the DISTANCE program to produce line transect densities. One drawback of line transect analysis is that considerably more time is necessary to prepare and process the data.

In a monitoring program designed to detect trends in abundance, priority should be given to repeatable methods, both in the field and in analysis, and to minimizing variability due to sampling. Line transects, if data are collected and analyzed correctly, should produce more accurate densities, but both strip and line techniques are suitable for monitoring trends. Sources of variability, and how to minimize variability due to sampling and analysis, warrant further examination beyond the scope of this report. I recommend that line transect data continue to be collected on Marbled Murrelets. I further recommend that 1) some detailed standards and criterion be established in the use of DISTANCE, 2) analyses should be performed by one or a group of experienced persons to maintain a high level of consistency and expertise in the analytical approach, and 3) strip transect densities should also be computed as a check on the validity of program results. Strip transects are the only practical means of collecting consistent density data for several species (such as the other alcids).

The quantification of a behavioral component in age determination is a new technique. The probability of correct age determination based on the post-dive flapping behavior can probably be improved above 80% with more standardized observations. Advanced molt AHY were reluctant to dive and quick to shed water by flapping when they surfaced. This suggests a physiological or energetic need to minimize water contact at this stage of the molt. Of the AHY which did not flap, some were pressed by the proximity of our vessel to dive again immediately, and others were in the final stages of molt, and did not have the physiological impulse to shed water, as appears to be the case with HY.

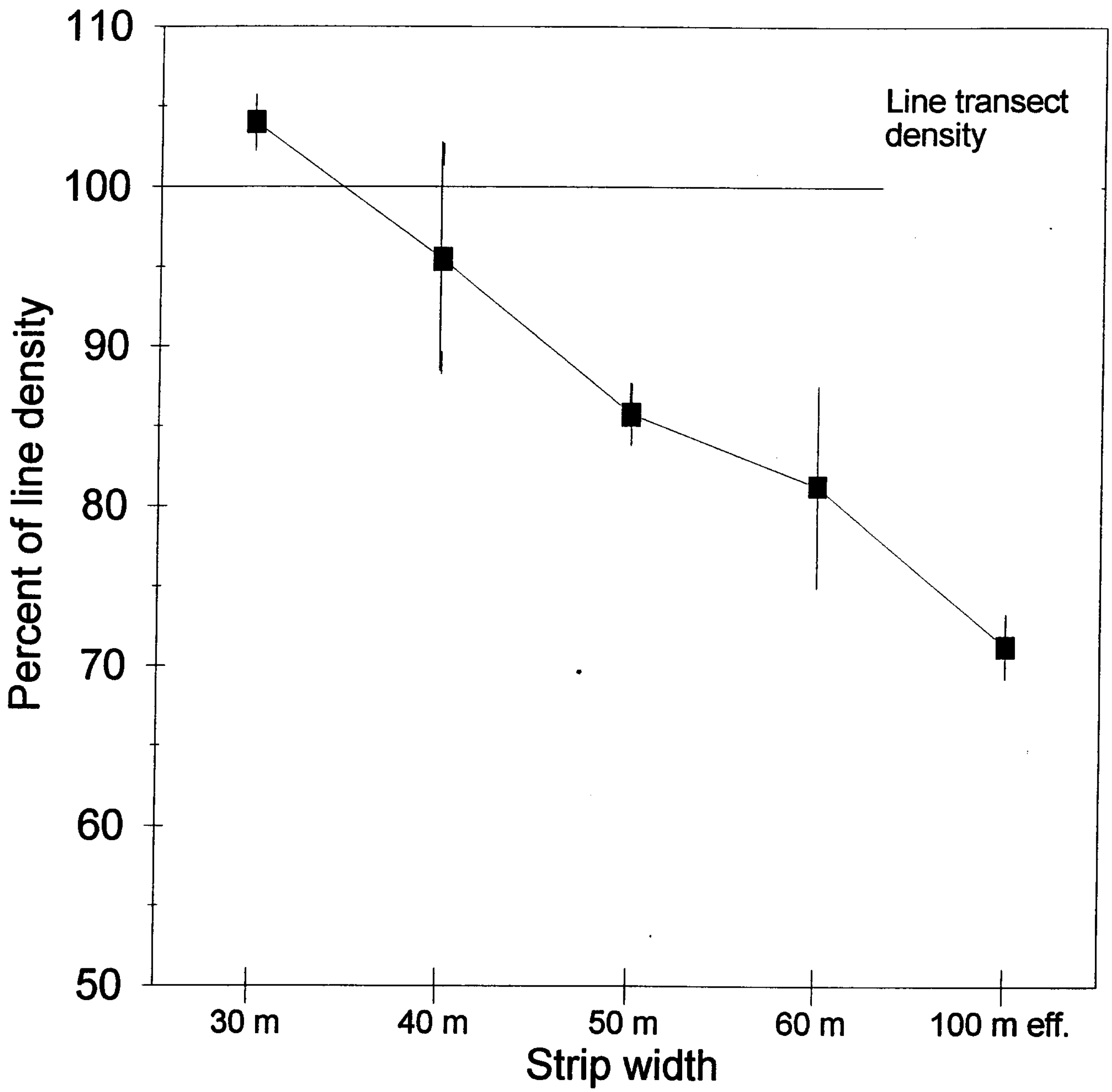

Figure 1. Marbled Murrelet densities generated using 5 strip widths as a percentage of the density generated by DISTANCE. Data are mean values ± one standard error from 29 transects of varying length.

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